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Erosion in the hydrographic basin of the Arkansas river above Little Rock.

The Wilder Quarter-Century Book,
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OBSERVATIONS
UPON THE EROSION
IN THE
HYDROGRAPHIC BASIN OF THE ARKANSAS RIVER
ABOVE LITTLE ROCK

BY

JOHN CASPER BRANNER, PH.D.

REPRINTED FROM
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OBSERVATIONS UPON THE EROSION IN THE HYDROGRAPHIC BASIN OF THE ARKANSAS RIVER ABOVE LITTLE ROCK.

By JOHN CASPER BRANNER.

In October, 1887, I began and carried on for one year a series of observations upon the Arkansas River at Little Rock, for the purpose of determining the efficiency of that stream as an agent of erosion and transportation. These observations consisted of a series of thirty-two measurements of discharge, three hundred and sixty-five gage readings, one hundred and seventy-nine determinations of matter carried in suspension, and a similar number of determinations of matter carried in solution by the river water. These observations were so distributed as to be as comprehensive as possible, embracing all the varying conditions of weather, temperature and rainfall; when the river was rising, when it was falling, when at a standstill; when low, when high, and whenever there was any considerable change in the volume or character of the water.*

Method of Observation.†—A cross-section was carefully measured 1,200 feet above the upper bridge, a place in the river where there was least chance of any marked change occurring within the time occupied by the observations. At the place selected one bank is of rock and the other of tough clay. Floats were sent through this section at transverse intervals of twenty-five to fifty feet, and their positions as they crossed the section were located by a transit, and the time occupied in floating one hundred feet was noted. Wooden rods twelve feet in length were used as floats. These rods were two inches square at one end, from which they tapered the whole length of the rod to a sharp point at the other. They were weighted so as to float upright and to leave the pointed end about two feet out of the water to serve as a signal. Where the rods could not be used on account of shallow water, a surface float with a weight attached by a cord was substituted. From the data thus obtained the volume of the river was deduced. Sets of samples of the water were taken along the cross-section at the time of the velocity observation, each set being in three parts, one each from the surface, mid-depth, and three feet from the bottom. In collecting the sample from the bottom, in order to avoid taking it from the liquid mud usually present next to the bottom, the collecting apparatus was so arranged that the sample was taken three feet from the actual bed of the stream. In order to avoid the possible mingling of the water from lower depths with that above, and to insure that the samples fairly represented the part of the stream from which it was taken, an open glass tube holding one liter was used for a collecting vessel. This was so arranged as to close securely by means of two rubber balls. When a sample was to be taken, the stoppers were caught back, leaving the ends of the tube entirely unobstructed; the tube was then sunk by means of a rod, care being taken to keep its axis parallel with the current of the stream. By means of a gage the depth to which it was desired to sink it was determined. When the vessel reached the desired point, a jerk of the string released the rubber balls, which closed the ends of the tube and confined in it a representative of the part of the stream from which it was taken. The samples were always taken at the time the volume of the stream was being measured. They were placed in separate, clean bottles for examination.

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* This paper deals only with such conditions and changes as are possible in a given section; it does not consider the effects of curves or varying depths of the channel.

† The field observations were entrusted to Assistant Chas. E. Taft, an able civil engineer of wide experience.

In order to determine the amount of matter carried in mechanical suspension these samples were all taken to the laboratory and filtered until the water was perfectly clear; the filter containing the suspended matter was then dried, and weighed at the temperature at which it had previously been weighed. The amount of matter in solution was determined by evaporating the filtered water. These determinations were made for every sample collected during the year—358 determinations.* A daily record was also kept of the stage of the river during the time covered by the investigation.

These observations furnish data for the approximate determination of the discharge of the Arkansas River, and of the amount of material carried by it, both in suspension and solution, past Little Rock, during the year in which the observations were made (1887–8).

Suspended Matter.—The color of the water of the Arkansas River is due to mineral matter carried in mechanical suspension. It is more or less muddy all the year round, and even at its lowest stages, when it carries least sediment, it is not quite clear. Its color is ordinarily a yellowish brown, but it sometimes becomes dark red, at which times it carries such a large amount of mechanical sediments as to render it opaque, even as seen in an ordinary test tube.

The laws of erosion and transportation naturally lead one to expect a large amount of mechanical sediments to be removed when the volume of water or discharge is greatest. If the conditions which supply sediments to the stream were constant, this would undoubtedly be true, but the conditions are not constant, and the amount of material moved depends upon the sediment-supplying conditions rather than upon the transporting power of the water.

The matter in suspension is greatest during a sudden high rise; but after the water in the stream stands at any high mark for a few days, the decrease of the amount of suspended matter it carries is very marked. This contrast is most noticeable during the winter, probably because the frosts loosen up the surface soil and leave it in a condition favorable for ready transportation. The amount of sediment carried by the river varies widely also with the same gage reading at any stage, being greater with a rising, and less with a falling river.

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* The laboratory determinations were made under my personal direction by Dr. R. N. Brackett. All the care required by quantitative chemical analyses was taken with this work.

The lowest stages of the river are usually during the latter part of the summer and in the fall of the year. At such times the water becomes nearly but not quite clear. This clearness is due partly to a decrease in the volume and consequently in the velocity and carrying power of the water, and also to the large amount of common salt, lime, etc., in solution in the water, which substances tend to flocculate and precipitate the mechanical sediments. The greatest amount of mechanical sediment found in the water during the year under consideration was 225 grains to the gallon; this was on the second of May, 1888, when the river stood at seventeen feet on the gage, and shortly after protracted rains over the whole or nearly all the hydrographic basin of the Arkansas River above Little Rock. It should be added, however, that while this high water may be taken as a type of the ordinary rises, there are times when there is but little or no rise, no increase in the volume of water discharged, but a very marked increase in the amount of mechanically suspended matter. In October, 1891, occurred one of these so-called "red rises" of the Arkansas River, and although the river was quite low—marking only 3.9 feet on the gage—it carried out 761 grains of matter to the gallon, of which only 48 grains was matter in solution. Such a condition of the water is said to be due to rainfalls on the Canadian River, an affluent of the Arkansas, which runs through the "red beds" of western Indian Territory. This illustrates well the fact to which attention has already been called* that the sediments removed bear no constant relation to the discharge.

The total amount of suspended matter estimated by the above methods to have been carried down by the Arkansas in 1887–8 was 21,471,578 tons. This estimate, however, must be regarded as far short of the truth, for the method of taking the water samples has left out of account that stream of almost liquid mud and sand that is pushed along the bed of the river at all stages, but especially during high water, and which adds enormously to the amount of material daily and hourly carried out of the hydrographic basin of the Arkansas River above Little Rock.*

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* Annual Report, Chief of Engineers, U. S. A., 1874, I, p. 863; 1875, I, p. 966; 1877, I, p. 433; Physics and Hydraulics of the Miss. River, 1876, p. 417.

Character of the Sediments.—The matter in mechanical suspension in the river water is both sand and clay. Samples taken from the thread of the stream are mainly of fine sand, but samples of sediments allowed to settle in the quiet eddies of the river show that the lighter and more flocculent sediments sink to the bottom only in the quiet portions of the water.

An analysis was made of the sediments collected in six samples of river water of the 11th of April, 1888, two each from top, middle, and bottom of the stream.

ARKANSAS RIVER SEDIMENT FROM THE STREAM.†

Sand and insoluble matter, ...	85.18 per cent.
Soluble matter, ...	14.82 "

The soluble portion contained :

Iron oxide, (Fe_2O_3), ... Alumina, (Al_2O_3), ...	4.96 per cent.

On this occasion the river was very high, standing at 17 feet on the gage, but it had been higher by half a foot two days before.

A complete analysis was made of the sediment collected with six litres of water May 2d, 1888, when the river stood at 17 feet on the gage after a sudden rise, and while the rise was still in progress. It is as follows :

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* In the Annual Report of the Chief of Engineers, U. S. A., 1875, II, p. 478, Col. J. H. Simpson shows how sand-bars travel down-stream. See also Physics and Hydraulics of the Miss. River, by Humphreys and Abbot, 1876, p. 147.

† Analysis by Assistant Dr. Jas. Perrin Smith.

ANALYSIS OF ARKANSAS RIVER SEDIMENT.[*]

	Per cent.
Silica (SiO_2)	69.53
Alumina (Al_2O_3)	11.65
Iron (ferric) oxide (Fe_2O_3)	4.46
Carbonate of lime ($CaCo_3$)	6.62
Carbonate of magnesium ($MgCo_3$)	3.52
Potash (K_2O)	.66
Soda (Na_2O)	1.14
Organic and volatile matter	2.95
Total	100.58

These analyses, together with a large number of washings of the sediment, show that its chief constituent is quartz sand. There is always more or less clay in the water.

The Finer Sediments.—Experiments have already been made by other observers which show that extremely fine material held in suspension by water may be retained in suspension for an indefinite length of time.[*] The observations upon Arkansas River water point to the same conclusion. A glass jar one metre in length and holding six litres, was filled with turbid water taken from the river October 10th, 1887, and was allowed to stand in the Survey office until January 16th, 1888. Within four days after it was filled the water had become comparatively clear. Very fine particles continued, however, to float about in it until January 15th. That night the weather was cold enough to freeze and feathery ice crystals penetrated the whole body of the water. As soon as the room was warmed and the ice melted, the matter in suspension was found to be collected in masses resembling strings of cobwebs, in which form it clung to the sides of the jar or sank to the bottom, leaving the water perfectly clear.

Dissolved Matter.—The matter in solution bears no constant relation to the volume of water, though in a very general way it varies inversely with the volume of the water, and ranges from 11 to 70 grains to the U. S. gallon. This dissolved matter is principally chlorides of sodium, potassium, and magnesium, and the carbonates of lime, soda, and magnesia. At low stages of the river there is enough sodium chloride in the water to give it a decidedly brackish taste. The analyses given below represent high and low stages of the water.

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[*] Analysis by Assistant, Dr. J. P. Smith.

[†] On the subsidence of particles in liquids, by Prof. Wm. H. Brewer, Memoirs Nat. Acad. Sci., Vol. II, p. 165.

Subsidence of fine solid particles in liquids, by Carl Barus, U. S. Geological Survey, Bulletin 36, 1886.

ANALYSIS OF FILTERED ARKANSAS RIVER WATER.

(Sample collected December 20th, 1888, when the river stood at nine feet on the gage).

Hypothetical Combination.

		Grains per U. S. Gallon.	*Per cent. of Solids.*
Silica	(SiO_2)	.75	11.81
Chloride of sodium	($NaCl$)	1.96	30.87
Chloride of potassium	(KCl)	.44	6.93
Sulphate of magnesium	($MgSO_4$)	.14	2.20
Sulphate of iron	($FeSO_4$)	.43	6.77
Sulphate of alumina	($Al_2(SO_4)_3$)	.15	2.36
Carbonate of soda	(Na_2CO_3)	1.07	16.85
Carbonate of magnesia	($MgCO_3$)	.28	4.41
Carbonate of lime	($CaCO_3$)	1.13	17.80
Total,		6.35	100.00

Found.

Silica	(SiO_2)	.75	11.83
Sulphuric acid	(SO_3)	.51	8.04
Carbonic acid	(CO_2)	1.48	23.34
Chlorine	(Cl)	1.39	21.92
Iron	(Fe)	.16	2.52
Aluminum	(Al)	.02	.32
Calcium	(Ca)	.45	7.10
Magnesium	(Mg)	.11	1.73
Potassium	(K)	.23	3.63
Sodium	(Na)	1.24	19.57
Total,		6.35	100.00

ANALYSIS OF FILTERED ARKANSAS RIVER WATER, LOW STAGE.

(Sample collected August 22d, 1888, when the river stood at 2.4 feet on the gage).

Hypothetical Combination.

		Grains per U. S. Gallon.	*Per cent. of Solids.*
Silica	(SiO_2)	.85	1.83
Chloride of sodium	($NaCl$)	28.57	61.58
Chloride of potassium	(KCl)	.68	1.47
Sulphate of magnesia	($MgSO_4$)	3.92	8.45
Sulphate of lime	($CaSO_4$)	.75	1.62
Sulphate of iron	($FeSO_4$)	05	.11
Sulphate of alumina	($Al_2(SO_4)_3$)	.38	.82
Carbonate of lime	($CaCO_3$)	8.47	18.26
Total,		46.36	100.00

Found.

Silica	(SiO_2)	.85	1.83
Sulphuric acid	(SO_3)	5.90	12.73
Carbonic acid	(CO_2)	5.08	10.96
Chlorine	(Cl)	17.62	38.91
Iron	(Fe)	.02	.04
Aluminum	(Al)	.06	.13
Calcium	(Ca)	3.56	7.68
Magnesium	(Mg)	.78	1.68
Potassium	(K)	.35	.75
Sodium	(Na)	12.14	26.15
Total solid,		46.36	100.00

It will be noticed that at the low stage of water 61.57 per cent. of the dissolved matter removed is common salt, and 8 per cent. is Epsom salt.

This dissolved matter is invisible and consequently not of a kind to attract so much attention as the mechanical sediments, but the total for a day, a month, or a year, is an impressive one. The amount carried down in this form from October, 1887, to September, 1888, was 6,828,350 tons, and averaged 569,029 tons per month ; during the single month of May, 1888, 1,161,160 tons were carried out in solution. When it is remembered that this material has all been dissolved from hard rocks within the drainage basin of the Arkansas River some conception can be had of the importance of this method of land degradation.*

The relation existing between the matter in solution and that in suspension is what one would naturally expect, viz.: when the river is high there is least dissolved and most suspended matter to the gallon of water, and *vice versa*. This, however, must be regarded as a very general rule to which there are many and important exceptions. The results for the month of April, 1888, will serve as an example of these relations.

During that month eight sets of observations were made with the following results:

TABLE SHOWING THE FLUCTUATING RELATIONS OF SUSPENDED TO DISSOLVED MATTER.

DATE, 1888.	Gage, ft.	Dis. cu. ft. per sec.	Grs. pr. U.S. gal.		Tons per day.		Total tons per day.
			Suspended.	Dissolved.	In Suspension.	In Solution.	
April 9.	5.75	19,608	29.41	15.41	26,619.1	13,947.7	40,666.8
" 13.	13.65	62,128	85.60	11.00	235,486.1	31,546.1	267,032.2
" 14.	16.30	92,199	122.50	13.60	519,858.9	59,880.3	579,739.2
" 16.	17.00	98,233	174.30	15.30	793,852.0	68,176.8	862,028.8
" 18.	13.35	65,512	112.60	15.70	340,517.5	47,478.9	387,996.4
" 21.	10.70	38,365	58.50	15.00	103,595.8	26,563.0	130,158.8
" 25.	6.20	17,627	45.17	43.76	36,753.1	35,605.9	102,459.0
" 28.	5.50	16,214	31.83	42.53	23,822.8	31,831.1	55,653.9

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* But little attention has been given to the determination of mineral matter removed in solution from the land. The observations of hydraulic engineers to whom we are indebted for the determination of mechanical sediments, have not included the discharge of matter in solution, for the reason, no doubt, that they have had to deal practically with the mechanical sediments only.

Taking the observations for the entire year under consideration, the matter in solution is equal to about .31 of that in suspension, or a little more than one-fourth of the total amount removed. These relations, however, are not constant, as may be seen by a comparison of the totals in suspension and solution during the individual months or on individual days. In November, 1887, for example, the dissolved matter was greatly in excess of the suspended matter—more than six times as much—while on Oct. 13th, 1891, the suspended matter was more than thirteen times the matter in solution.

Attention is called to the larger percentage of silica in the water in times of freshets ; 1.83 of the total at low water, and 11.81 of the total at high water.* The water at low gage readings is all spring water, or water that has passed through the rocks or soils instead of over them, while that at high readings is chiefly surface water. It seems probable, therefore, that the silica exposed over the surface of the ground is rendered more soluble by its exposure to weathering influences and to the organic acids of decaying organic matter, than is that of the unexposed rocks through and over which underground waters pass.

The Results.—The following tables are based upon gage readings for every day of the year, a complete set of velocity and discharge observations made and comprehensive samples of water collected on 32 days. From these observations interpolations were made to complete the table. The results of two independent sets of interpolations agree closely.

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*Inasmuch as only one pair of analyses was made to determine this point it is possible that a generalization on this subject is not to be trusted, in any case it is desirable that other observations be made on this subject.

MATERIAL CARRIED BY THE ARKANSAS RIVER PAST LITTLE ROCK DURING THE YEAR 1887-8.

1887.	*Tons in Suspnesion.*	*Tons in Solution.*	*Tons in Suspension and Solution.*
October, . . .	377,557.2	354,171.9	731,729.1
November, . .	16,449.9	102,082.4	118,532.3
December, . .	700,558.2	444,062.5	1,144,620.7
1888.			
January, . . .	230,400.4	481,925.9	712,326.3
February, . . .	999,398.0	468,320.5	1,467,718.5
March, ...	2,391,281.0	666,753.5	3,058,034.5
April, ...	4,381,629.2	818,474.6	5,200,103.8
May, ...	6,208,717.0	1,161,160.0	7,369,877.0
June, ...	4,467,377.4	860,214.0	5,327,591.4
July, ...	296,234.2	499,869.2	796,103.4
August, ...	121,955.5	383,369.5	505,324.0
September, . .	1,280,020.6	577,946.4	1,857,967.0
	21,471,578.	6,828,350.	28,299,929.

The total bulk of this material would make a cube whose sides would be 749.2 feet in length.* The total suspended

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* The specific gravity of the suspended matter is assumed to be 2.13—an assumption based upon an average of seven determinations of the specific gravity of Arkansas River sediments. It is worthy of note that six of the samples used in these determinations were taken from sediments deposited naturally along the river, and one of them was taken from the water used in making the laboratory determinations on sediments. The specific gravity here used is therefore somewhat too high.

DETERMINATIONS OF SPECIFIC GRAVITY OF ARKANSAS RIVER SEDIMENTS.

No. 1.—Sp. gr. 1.7921. Collected Nov. 13, 1888, about 40 feet east of the St. Louis, Iron Mountain, and Southern Railway bridge (upper bridge) on the north bank of the river within a few feet of the water's edge.

No. 2.—Sp. gr. 1.7764. Collected Nov. 13, 1888, about 100 feet east of the St. Louis, Iron Mountain, and Southern Railway bridge on the north bank of the river.

No. 3.—Sp. gr. 1.8043. Collected Nov. 13, 1888, about 40 feet west of the St. Louis, Iron Mountain, and Southern Railway bridge, on the north bank of the river.

No. 4.—Sp. gr. 1.8014. Collected Nov. 13, 1888, about 100 feet west matter, if spread over the hydrographic basin of the Arkansas River above Little Rock*—140,000 square miles—would have a thickness of .000,082 of a foot; the total dissolved matter would have a thickness of .000,024 of a foot, or the total suspended and dissolved matter would be .000,106 of a foot in thickness. Erosion over this area during the year 1887–8 therefore took place at the rate of one foot in 9433 years.

The interpolations made in the observations on sediments discharged, necessarily detract from the value of the conclusions reached in regard to the quantity of material carried out of the basin. These conclusions must, therefore, be accepted only with the confidence to which the methods followed in the work entitle them. The means at the command of the Geological Survey did not permit the exhaustive observations that were desirable; indeed, that a thoroughly satisfactory set of observations should be made with the modest appropriation of a state Geological Survey is quite out of the question. The observations have some value, however, on account of their never having been made at this point† be-

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of the St. Louis, Iron Mountain, and Southern Railway bridge on the north bank of the river.

No. 5.—Sp. gr. 1.8090. Collected at the foot of Spring St. on the south bank of the river. A cube of 21.9 grams was dried at 120° C., and allowed to stand several days in the air.

No. 6.—Sp. gr. 1.17603. Collected Nov. 13, 1888, about 15 feet east of the St. Louis, Iron Mountain and Southern Railway bridge on the south bank of the river.

Nos. 1, 2, 3, 4, and 6 were air-dried.

No. 7.—Sp. gr. 2.5632. A mixture of the sediment from six bottles of water collected for sediment determinations, May 2, 1888.

The specific gravity of the dissolved matter is assigned it from the specific gravities of the constituents (in their proper proportions) found by analyzing the filtered water.

* The area of the hydrographic basin above Little Rock was kindly furnished by Henry Gannett of the U. S. Geological Survey. Other estimates make it somewhat larger.

† The investigations of Humphreys and Abbot include a series of discharge and current measurements on the Arkansas River at Napoleon. As those authors point out, however, (Physics and Hydraulics of the Miss. River, 1876, p. 33) the water of White River was included in their

fore, and it is hoped that no other apology is necessary for their publication. But whether the work had been thoroughly comprehensive or not, it is evident from the behavior of this large stream, fed from such a large and geologically diversified hydrographic basin, that slight and even local changes of meteorologic conditions may greatly change the results obtained, or those that would have been obtained, had the observations been made daily instead of occasionally. The total here given for the year 1887–8 may be twice as large or but half as large as that for the next succeeding year even with the same or nearly the same discharge of water. For this reason no estimate of results for a longer period based upon these observations or estimate for any other period of time can be more than approximately correct, because the relations of the amount of matter carried either in solution or suspension to the volume of water are not constant. A perfectly satisfactory measure of the actual work done by such a stream can only be determined by a series of observations covering a number of years, and made in connection with careful meteorologic observations during the same period over the entire hydrographic basin. It is also evident that deductions derived from observations upon the Arkansas River are not applicable to the study of other streams except in a very general way.

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measurements, although that stream can scarcely be regarded as a tributary of the Arkansas. Their results must have been considerably modified by the presence of so large a body of comparatively clear water.

PALO ALTO, CALIFORNIA,
AUG., 1893.

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